DENSITY CONTROL HANDBOOK

November 2003

A Guide to Density Testing of Soils and Hot Mix Asphalt (Bituminous) Materials for Construction Inspectors

Michigan Department of Transportation

CONSTRUCTION AND TECHNOLOGY
GEOTECHNICAL SERVICES UNIT
DENSITY TECHNOLOGY GROUP

FOREWORD

This handbook has been prepared for training Michigan Department of Transportation construction technicians, and for on-the-job reference concerning density testing procedures for soils and Hot Mix Asphalt (bituminous) mixtures. It reflects current Michigan Department of Transportation practice, as based on past experience and on recognized national standards in testing procedure.

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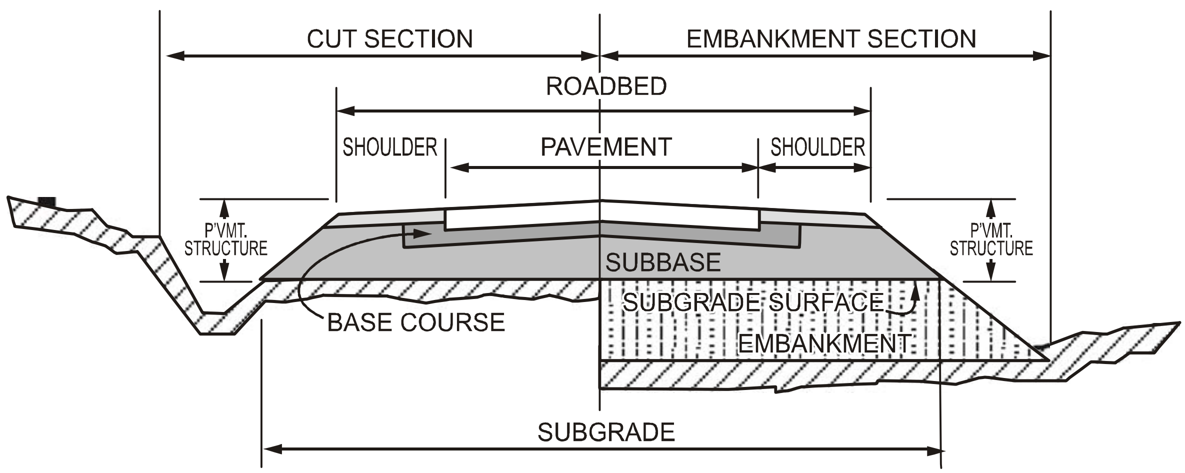

Road Section Nomenclature

GENERAL INFORMATION

1. SOILS

Soil is a natural body occupying the portion of the earth mainly composed of mineral and organic materials and, unless otherwise specified, may include any unconsolidated deposit down to hard rock. Soils, as found in the field, are mixtures of soil particles, air, and water. The soil particles are classified as clay, silt, and sand and these are called soil separates. Clay is the finest grain size, silt is the next finer, and sand is the most coarse.

Texture Classes are also called clay, silt, and sand. They are so classified because they carry the predominant characteristics of the soil separate name they are identified with. A clay soil is very sticky when wet and lumpy when dry. It has strong cohesion (attraction between particles) and is commonly called a cohesive soil. Clay soils have relatively high natural moisture contents. Silt is floury in appearance, has a talcum powder "feel," and a great affinity for retaining water. Sand is a non-cohesive soil which is not sticky when wet and very loose and fluffy when dry. The natural moisture content of sand is relatively low as compared with clays.

Soil mixtures may also contain some amounts of gravel, which is a granular material. By AASHTO definition gravel will pass the 3 inch (75 mm) sieve and be retained on the No. 10 (2 mm) sieve. Cobbles and boulders are larger rocks which may also be present in soils.

For the purpose of this handbook, the term "soil" refers to mixtures of soil, air, and water. The terms clay, silt, and sand refer to their textural class.

2. HOT MIX ASPHALT (BITUMINOUS) MIXTURES

Hot Mix Asphalt (bituminous) mixtures are hot plant-manufactured materials. The mixtures consist of predetermined amounts of sand, stone, fines, and bitumen. The mixtures could also consist of various amounts of recycled materials.

Delivered to the job site, the Hot Mix Asphalt (bituminous) mixtures are placed in layers and are normally used as bases, binders, leveling, and top courses.

3. STABILIZED MIXTURES

Stabilized mixtures consist of any existing material which is retextured or mixed with a stabilizing agent.

The most common method of stabilization consists of mixing hot bitumen with an existing mixture of ground-up Hot Mix Asphalt (bituminous) surface and aggregate base. The layer of stabilized material is then used as a base course for a new Hot Mix Asphalt (bituminous) surface. Stabilization increases the bearing capacity and stability of the existing material and reduces reflective crack patterns normally associated with resurfacing projects.

4. PULVERIZED PAVEMENT MIXTURES

Pulverized pavement mixtures consist of existing Hot Mix Asphalt (bituminous) and/or concrete surfaces, pulverized and mixed with some portion of the underlying aggregate base.

The resulting mixture of pulverized Hot Mix Asphalt (bituminous) or concrete and aggregate base material is then compacted and used as a base course for new or recycled pavement surfaces. This is another method of recycling existing Hot Mix Asphalt (bituminous) and concrete surfaces by utilizing existing material and increasing the load carrying capacity of the resulting new pavement.

5. DENSITY

Density is a ratio expressed by the formula $D=W / V$ or density equals the weight of material divided by the volume it occupies. A simple example is the density of water. Each cubic foot of water weighs 62.4 pounds; thus, the density of water is 62.4 pounds per cubic foot. When working in metric units, density is expressed in kilograms per cubic meter (kg/m^3). In soil testing, density is used to determine the degree of compaction by comparing the In-Place Density to the Maximum Density. The degree of compaction, expressed as a percent, is then compared to the specification requirement to determine pass or fail. Maximum Density is a standard expressed in pounds per cubic foot or kilograms per cubic meter which is arrived at by applying a standard compactive effort to a soil mixture under controlled conditions.

6. COMPACTION

Compaction is the elimination of excess air spaces (voids) in a soil by mechanical means. Vibration is a good mechanical means in sand soils; compression and impact are more successful means of compaction in clay soil. Some common types of equipment used for compaction on sand are track-type dozers, vibrating rollers, wobble-wheel rollers, and plate-type vibrators. Common types of equipment used on clay are sheepsfoot rollers, rubber-tired rollers, and rubber-tired hauling equipment. To obtain a desired amount of compaction, it may be necessary to lower or raise the moisture content in the soil.

Compaction of Hot Mix Asphalt (bituminous) mixtures is accomplished by the rearrangement of the particles to reduce the amount of voids to a predetermined percentage of the compacted mass. Bitumen is a thermoplastic liquid and as a lubricant in the arrangement of the particles, its temperature is critical. Compaction of the Hot Mix Asphalt (bituminous) mixture must be obtained while the bitumen is still hot and fluid.

Compaction of Hot Mix Asphalt (bituminous) mixtures is normally obtained in four stages: paver screed effort, breakdown rolling effort, intermediate, and clean up rolling effort. Rollers presently allowed are rubber-tired, steel-wheeled vibratory, and static rollers.

7. CONTROLLED DENSITY METHOD

The Controlled Density Method is the standard procedure used by the Michigan Department of Transportation to control the placement and compaction of embankment and backfill material. This method shall be used unless otherwise shown on the plans or in the proposal.

Material is placed in horizontal layers not exceeding a thickness of 9 inches (225 mm) for clay/cohesive soil or 15 inches (375 mm) for granular soil. The loose soil layer must be compacted by mechanical means to the minimum specified density. Each layer is tested and accepted before the succeeding layer is started. The equipment used to spread the material and the type of equipment used to compact the material is determined by the contractor. The primary requirement is that the material be placed in discreet horizontal layers and uniformly compacted to the specified density throughout the fill area.

Where tests indicate inadequate density, it is generally due to one of two reasons:

1. Improper moisture content
2. Insufficient compactive effort.

Improper moisture content is the greatest single cause of difficulty in attaining the specified density requirement, especially for cohesive soil. MDOT specifications require that cohesive soils have a moisture content not greater than 3 percent above optimum at the time of compaction, except for the top 3 feet (1 m) of embankment which shall not exceed optimum. If the material contains excessive moisture, it must be aerated and dried by disking or other effective methods before being compacted. Sometimes, where large areas of embankment are to be constructed, a layer of wet material may be left to dry while placing or compacting operations are alternately being performed at another embankment area. Because the natural moisture content of clay soil is often near optimum or above optimum, the addition of water is generally not required. However, if the material is dryer than optimum, water may need to be added to facilitate compaction. The closer the moisture content is to optimum, the easier it is for the contractor to attain density. At times, where the cut material is composed of both wet and dry material, grading operations may require some mixing after the material is deposited on the grade and before compacting. Although it is generally not economically practical for the contractor, he may elect to waste the wet material and replace it with an equal volume of drier material. When atmospheric conditions permit little or no evaporation, wet material cannot be manipulated, aerated, and dried. During such periods, which generally include later fall, winter, and early spring, the contractor often chooses to wait for more favorable construction weather.

The compaction characteristics of sand soils are much less sensitive to moisture variation and sand can be satisfactorily compacted over a wide range of moisture content. In as much as the natural moisture of sand soils is often in a bulking range of 3 to 5 percent, compaction can often be attained more quickly and with less effort by adding water. Excessive moisture is generally not a problem with sands, except for saturated fine sand which has been excavated from below the water table. In this case, the usual solution is to allow the material time to dry to a moisture content less than optimum before placement and compaction are attempted. The compaction of granular material can generally be conducted in wet weather and sometimes even in freezing weather.

At times, the soil of the original ground contains enough moisture to become spongy when trying to place the first layer of an embankment, making compaction almost impossible. If this spongy condition is not corrected, the embankment will usually continue to be spongy with each succeeding layer. Sometimes it is possible to remedy this problem by disking and aerating the original ground. If the original ground contains an excess of moisture so that manipulation is not practical, it may be necessary to construct the first layer of Granular Material Class III to the minimum elevation at which the equipment can be operated.

When the moisture of the embankment material is at or near optimum, the contractor should have little difficulty in obtaining satisfactory density if adequate compactive effort is applied. When modern, heavy earthmoving equipment places the material in thin layers over a large area, and if the units break track for maximum compactive coverage, they can usually attain satisfactory compaction alone. A common problem occurs when many units are hauling a short distance to a small embankment area. To obtain uniform compaction, supplemental compaction equipment must be added.

Whenever density tests indicate that the contractor has not obtained the specified density, he must be advised that the succeeding layer may not be placed until the specification requirement is met. The decision as to how the corrective work is to be done is left up to the contractor. From the test results and from observation, however, the inspector should recognize the reason for the low density and could suggest appropriate action such as disking the wet soil to dry it, adding water to a dry soil, or simply doing more rolling if moisture is not a problem.

While specifications permit the placement of clay in layers up to 9 inches (225 mm) thick and sand in layers up to 15 inches (375 mm), better results are obtained if the material is spread and compacted in thin lifts. Layers 3 to 5 inches (75 to 125 mm) thick require less compactive effort and promote better hauling conditions.

Modern, heavy earthmoving equipment generally causes some “kneading” or movement of a compacted clay fill under passing wheel loads even though the soil is at Optimum Moisture. In all but dry cohesive soils a moderate amount of such movement is to be expected and is not detrimental. In general, the surface should rebound after the wheel passes and should not leave ruts more than 1 to 3 inches (25 to 75 mm) deep. Occasionally, some sensitive clays are observed to rut deeply even though the density and moisture requirements are within specification. When such actions are observed, density test computations, procedures, and equipment should be reviewed to confirm that specification requirements are being met. The Area Density Supervisor should participate in this review. If the condition continues up to subgrade elevation, it is suggested that the Project Engineer consult with the Regional Soils Engineer to determine whether disking and drying should be performed to ensure a more firm subgrade.

Although the type of compaction equipment used is left entirely to the option of the contractor, experience has shown that certain equipment is more efficient for compacting one type of soil than another. A sheepsfoot roller, for example, is generally more effective in compacting clay than sand.

Vibratory equipment is very effective on granular soils and relatively inefficient for compacting clay. Heavy, multi-wheel, pneumatic rollers are effective for all types of soils. Small plate vibrations are generally more efficient than tampers for compacting granular trench backfill.

For many types of soil, the very top 2 inches (50 mm) or so of the layer being compacted remains loose until it has been confined by placement of the succeeding layer. For that reason, it is important that the loose surface be scraped away before the density test is taken.

Special problems and consideration arise when soil is placed and compacted during freezing weather. Winter construction is covered under “Winter Grading” in the Construction Manual.

8. THE DENSITY TEST

The Michigan Department of Transportation currently uses five main tests to control the compaction of soils, Hot Mix Asphalt (bituminous) mixtures and recycled mixtures: the One-Point T-99 (Proctor) Test, the One-Point Michigan Cone Test, the Michigan Modified T-180 Test, the Density In-Place (nuclear) Test, and the Twelve-Inch (300 mm) Layer Method Test. The full AASHTO T-99 Test and the complete Michigan Cone Test are used only as referee tests. About the only time the latter tests are used in the field is when a soil is encountered that will not fit the existing One-Point Test Charts. The Twelve-Inch (300 mm) Layer Method is only outside of the roadbed.

The One-Point T-99, One-Point Michigan Cone, Twelve-Inch (300 mm) Layer Method, and Michigan Modified T-180 Tests are used to determine Maximum Density of a soil material. The One-Point T-99 and One-Point Michigan Cone Tests are departmental adaptions of the Standard AASHTO T-99 and Cone Tests. The nuclear gauge is used to check density of material In-Place. The One-Point T-99 Test is used for cohesive soils such as clays and all other soils having a loss-by-washing of more than 15 percent. The One-Point Cone Test is used for sands and gravels having a loss-by-washing of 15 percent or less, including aggregate base courses and Granular Material Classes I, II, and III. The Twelve-Inch (300 mm) Layer Method uses either the T-99 or Cone Test, depending upon the loss-by-washing, and is established at field moisture content. The Modified T-180 Test is used on materials that are stabilized In-Place and on Pulverized Hot Mix Asphalt (bituminous) Mixtures. These soils terms are defined in the Appendix to this handbook.

TESTS TO DETERMINE MAXIMUM DENSITY

Material	Tests
Granular materials having 15% or less loss-by-washing	One Point Cone Test
Cohesive materials having more than 15% loss-by-washing	One Point T-99 Test
Pulverized Hot Mix Asphalt (bituminous) used as Aggregate Base Course	Michigan Modified T-180 Test
Crushed Concrete used as Aggregate Base Course	Michigan Modified T-180 Test
Stabilized In-Place Materials	Michigan Modified T-180 Test

9. EQUIPMENT

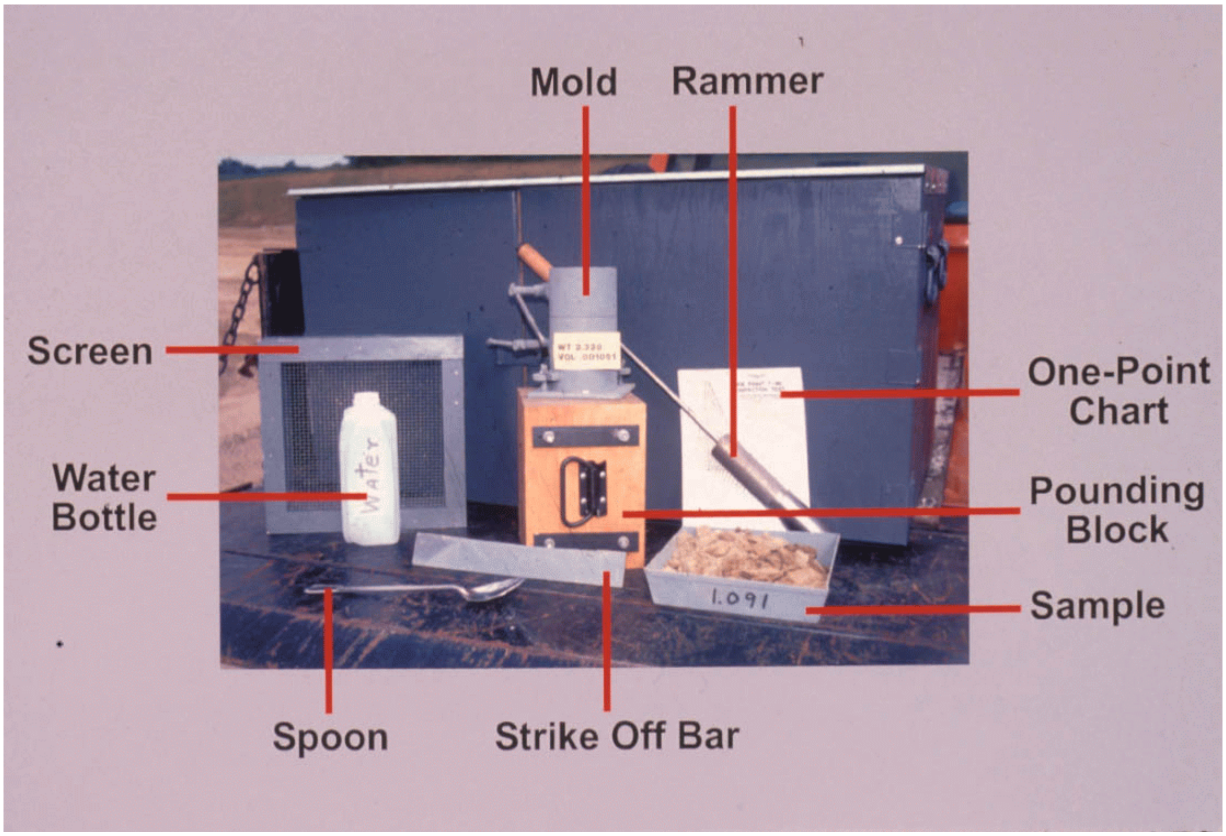

Figure 1. One-Point T-99 Test and AASHTO T-99 Test

Figure 1 shows the equipment used for the One-Point T-99 and the AASHTO T-99 Tests. It consists of a cylindrical mold (Proctor mold) 4 inches (100 mm) in diameter, with a detachable collar and base plate; a 5.5 pound (2.5 kg) rammer (or hammer device) with a 12 inch (305 mm) drop; a strike-off bar; a solid wood pounding block; a ¼ inch (6 mm) mesh screen mounted on a wood frame, and a water bottle.

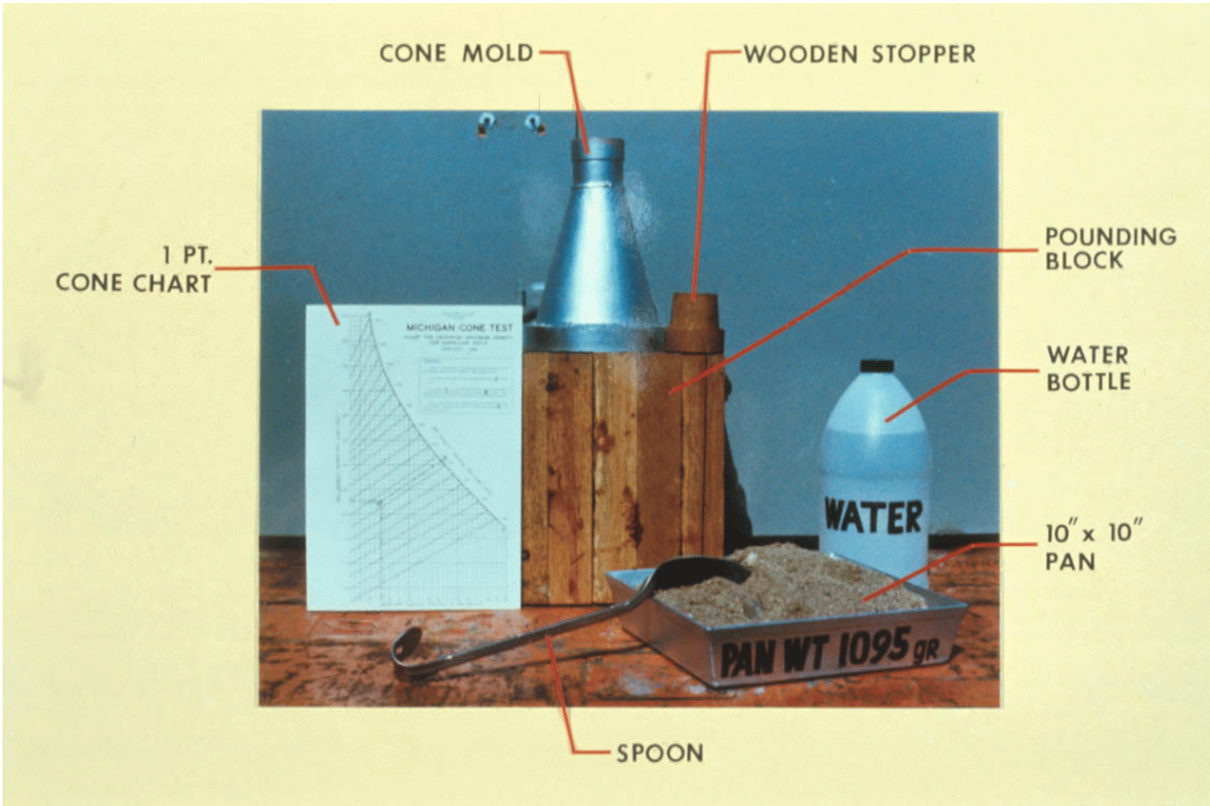

Figure 2. One-Point Michigan Cone Test and Michigan Cone Test

The equipment used for the One-Point Michigan Cone Test and Michigan Cone Test is shown in Figure 2, and consists of an inverted funnel mold commonly referred to as a “cone” having a solid bottom at a larger end, a hardwood pounding block, and a water bottle.

The Twelve-Inch (300 mm) Layer Method uses equipment of either the T-99 Test or the Michigan Cone Test depending upon the loss-by-washing of the soil being tested.

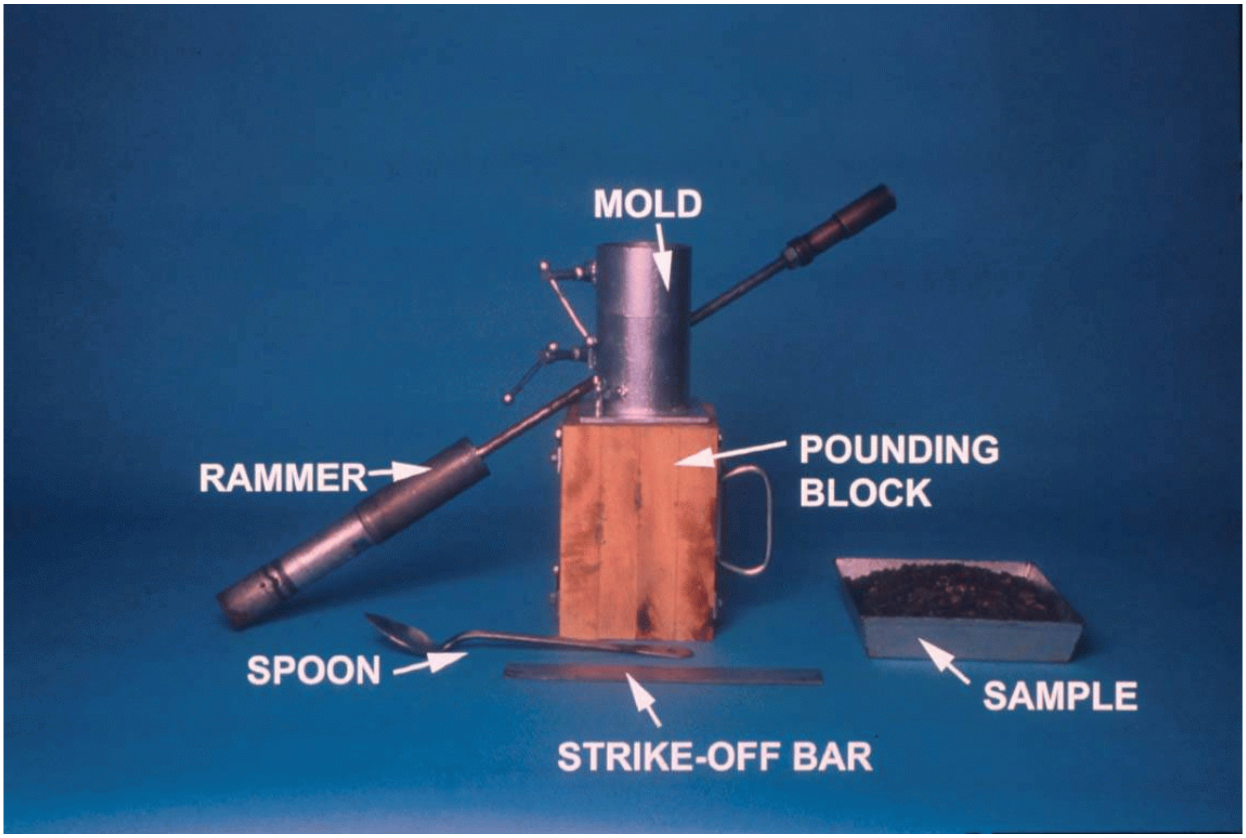

Figure 3. Michigan Modified T-180 Test

The Modified T-180 Test equipment shown in Figure 3 consists of the following: a wood pounding block, a cylindrical mold (Proctor mold) 4 inches (100 mm) in diameter, 10 pound (4.5 kg) rammer with an 18 inch (457 mm) drop, and strike-off bar.

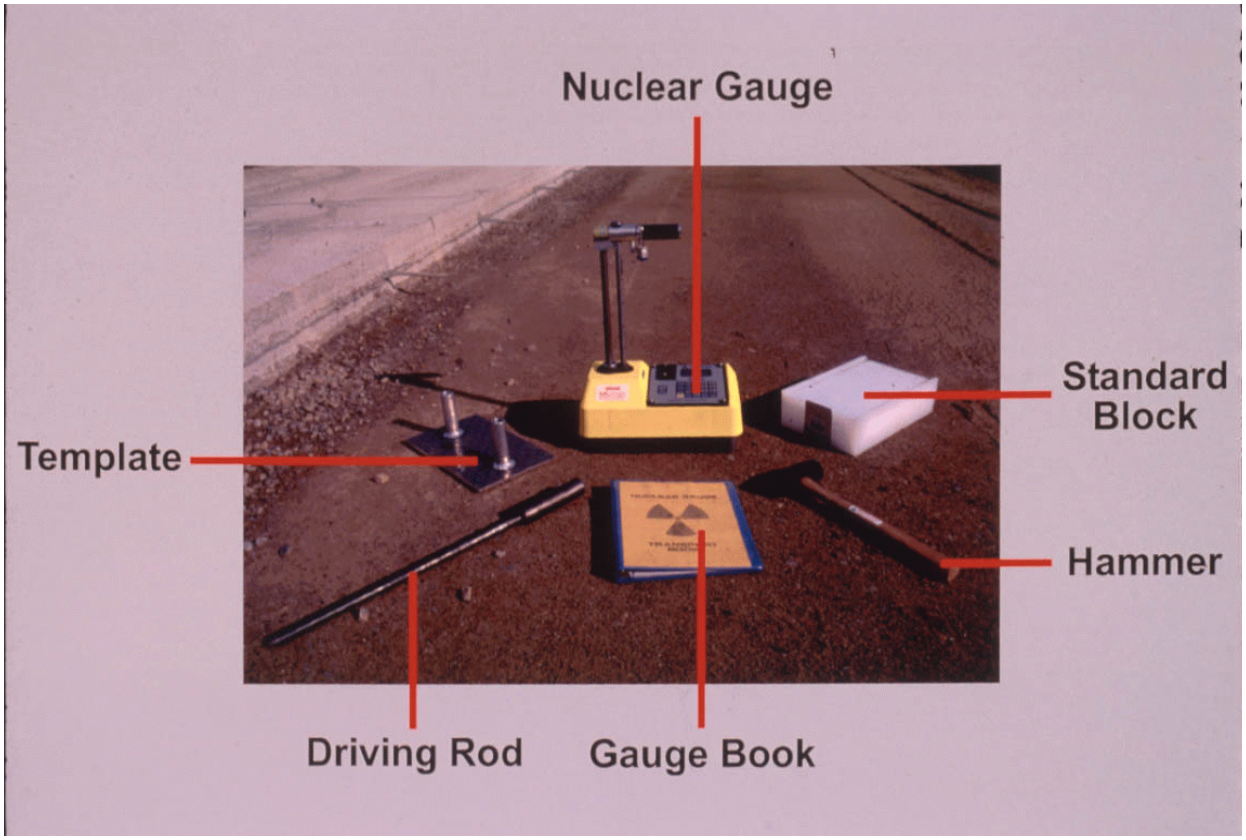

Figure 4. Nuclear Density In-Place Test

The density of material In-Place is determined by the use of a Nuclear Moisture-Density Gauge (Figure 4). The Michigan Department of Transportation currently uses one type of gauge, Troxler Model 3440. Other equipment used in this test include a gauge book, standard block, template, drill rod, and hammer.

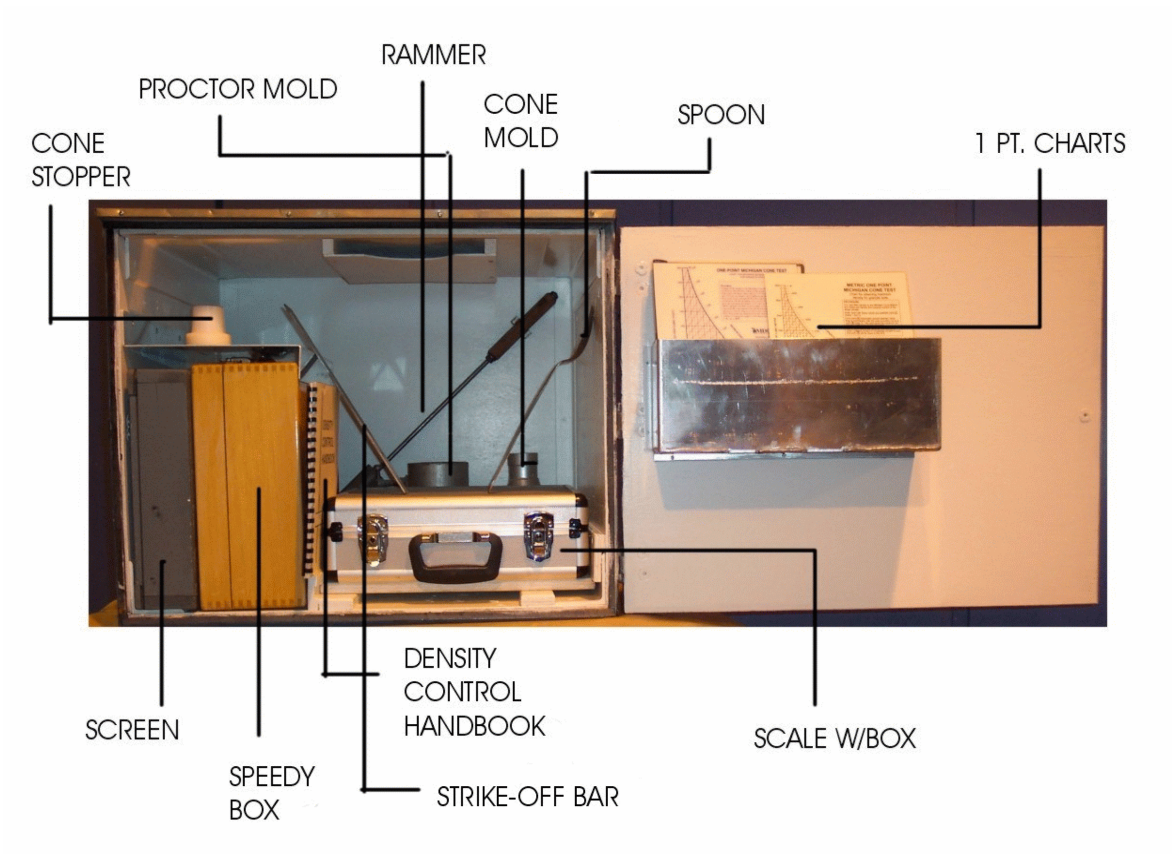

Figure 5. Contents of density box

A typical density box and detailed views of equipment contained in the truck-mounted density box are shown in Figure 5.

Figure 6. Troxler nuclear gauge in carrying case in the pickup cab

THE ONE-POINT T-99 TEST

1. DESCRIPTION

A Michigan adaptation of the AASHTO T-99 (Method C, Modified) Test is the "One-Point T-99 Test." The modification to the AASHTO test procedure is described in the Michigan Test Method (MTM) 404. The equipment used and the procedures for compacting the mold are the same as in the full AASHTO T-99 Test plus a One-Point T-99 Chart. The test name derives from the fact that only one mold need be completed. In Michigan, it is the primary test used to determine the Maximum Density of soils having a loss-by-wash greater than 15 percent.

Figure 1 shows the equipment used for the One-Point T-99 Test. It consists of a cylindrical mold (Proctor mold) of approximately 4 inch (100 mm) diameter, with a detachable collar and base plate; a 5.5 pound (2.5 kg) rammer, or hammer device, with a 12 inch (305 mm) drop; a sharp-edge strike-off bar; a solid wood pounding block; a ¼ inch (6 mm) mesh screen mounted on a wood frame; and a water bottle.

2. PREPARING AND COMPACTING THE SAMPLE

A representative sample, approximately 3500 grams, is taken from the In-Place Density test site. This sample should be thoroughly broken up by running it through the screen as shown in Figure 7. The coarse material retained on the screen is then visually inspected. Stones estimated to be larger than 1 inch (25 mm) are removed and replaced with an equivalent weight of smaller stone. The replacement stone shall be less than 1 inch (25 mm) but still large enough to be retained on the screen. This process must be completed as quickly as possible to avoid loss of moisture through evaporation. The coarse material retained on the screen is now added back to the sample.

Figure 7. Typical sample of approximately 3500 grams of soil after screening

The test should be started with the soil moisture content within a range from optimum to 4 percent below optimum. The closer to optimum the moisture content, the more accurate the test will be. With experience, the inspector can determine this by the texture, consistency, and appearance of the soil. It may also be determined by a simple hand cast test. Take a handful of the sample and squeeze it tightly in your fist to form a soil cast. If the moisture content is within the desired range, the cast will hold together firmly as shown in Figure 8 (left). Significant effort is required to break the cast as shown in the right half of Figure 8. If the sample is too dry, the cast will not form or will crumble easily when disturbed. If the sample is dry, more water should be added before the test is started. When water is added, the sample should be thoroughly mixed and run through the screen a second time. If the sample is too wet, the cast will mold very easily and may even feel sticky. The sample should then be dried by running it through the screen and spreading it out on top of the density box. This is particularly effective in hot weather.

Figure 8. Appearance of the soil cast between 4 percent below Optimum Moisture and Optimum Moisture (left), broken up under hand pressure (right)

The Proctor mold is then assembled and placed on a hardwood block (Figure 9) , supported on firm ground or existing pavements, but not on the tailgate of the pickup truck. A layer of soil is placed in the mold in quantity sufficient to fill one-third of its volume after compaction. The soil is then compacted in the mold by 25 blows of a 5.5 pound (2.5 kg) rammer weight, dropping 12 inches (305 mm) as shown in Figure 9. While compacting the soil, the rammer should be moved about the soil surface in the mold to obtain uniform compaction of each layer. It is important that the rod be held straight and the rammer weight dropped freely since it is a standard compactive effort. Any increase or decrease in the effort may materially affect the test's accuracy. A second layer of soil is added, filling another one-third of the volume of the mold after compaction. This, too, is compacted by 25 evenly distributed blows. The third and final layer is then added, including enough soil to extend slightly above the top of the mold, after compaction. The third layer is compacted by 25 evenly distributed rammer blows. After the collar has been removed, the compacted soil should extend ¼ to ½ inch (5 to 15 mm) above the top of the mold as shown in Figure 10 (top). If the soil does not extend above the mold or if the soil extends more than ½ inch (15 mm) above the mold, the test should be repeated.

The material is then struck-off even with the top of the mold using the strike-off bar, as shown in Figure 10 (bottom). If pebbles encountered at this level are disturbed, they may either be pushed down or replaced by soil pressed down firmly with the strike-off bar.

Figure 9. Proctor mold resting on a wood block

Figure 10 . After removing collar, compacted soil extending ¼ to ½ inch (5 to 15 mm) above mold's upper rim (top) is removed with strike-off bar (bottom)

DETERMINATION OF MAXIMUM DENSITY (Soil & Bituminous)									
			DENSITY DETERMINATION						
TEST NO.	MOIS-TURE %	VOLUME MOLD CU. FT.	WET SOIL + MOLD g	MOLD g	WET SOIL g	WET SOIL lbs.	COMPACTED SOIL WET PCF	MAX DENSITY PCF	OPTIMUM MOISTURE %
1	2	3	4	5	6	7	8	9	10
1	17.3	0.0363	4454	2495	1958	4.32	119.0	103.4	19.6

NOTE: To convert (g) to (lbs.): Wt. (g) ÷ 453.59 = Wt. (lbs.). To convert (m^3) to ($ft.^3$): Vol. (m^3) ÷ 0.02832 = Vol. ($ft.^3$).	
CHART STANDARDS	
DENSITY	MOISTURE
2757 / 2702	755 / 725
OPERATING STANDARDS	
DENSITY	MOISTURE
2710	736
BITUMINOUS MIX DESIGN PCF	

REMARKS

Figure 11. Entries and computations for the One-Point T-99 Test

3. WEIGHING THE SAMPLE

Next, the base plate is removed and the mold and sample are weighed to the nearest gram (Figure 12). This weight is recorded in Column D (Wet Soil + Mold) on Density Form 582B as shown in Figure 11. The volume of the mold and the weight of the mold when empty are painted on its side. The weight is recorded in Column E and the volume in Column C. The correct method of weighing is very important. If using a digital scale, be sure the scale is clean and level on a hard flat surface. When using a balance, the weights and sample should be centered on the scale pan, not scattered at random. Careless weighing procedures can cause significant differences in test results.

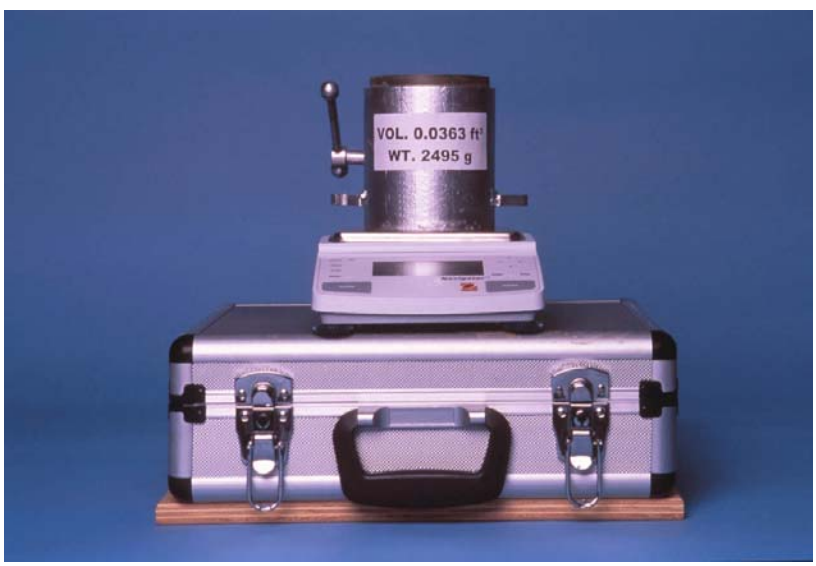

Figure 12. Weighing proctor mold with material on scale provided in the density box

4. MOISTURE DETERMINATION

If the moisture content of the sample was determined by the hand cast method to be within the appropriate range, from optimum to 4 percent below optimum, then the Moisture % from the In-Place Density Test is recorded in Column B on Form 582B (Figure 11). If the moisture content of the sample was adjusted before the mold was compacted, then the moisture content must be determined using the gas pressure meter ("Speedy"). Refer to section I, pages 1-12. Record the Moisture % in Column B. Place a circled "**S**" in the box to indicate that the Moisture % was determined by the gas pressure meter.

Complete the computations through Column H (Compacted Soil Wet) as shown in Figure 11. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing Column G (Wet Soil, lbs.) by the volume of the sample (Column C).

5. DETERMINING MAXIMUM DENSITY AND OPTIMUM MOISTURE

Maximum Density and Optimum Moisture are found by applying the Moisture % (Column B) and the Compacted Soil Wet (Column H) to the One-Point T-99 Chart, shown in Figure 16. As an example, assume that the results from a One-Point Test are as follows: Compacted Soil Wet (Column H) or "Wet Density" is 119.0 pounds per cubic foot (1930 kg/m^3) and the moisture content is 17.3 percent. Locate this moisture content on the horizontal leg (abscissa) and the Wet Density on the vertical leg (ordinate), and then project lines on the Chart as indicated by dashed lines **1** and **2** to an intersection **A**, Figure 15. Next, project point **A** upwards and to the right, as indicated by dashed line **3** to an intersection **B** with the solid outside boundary line. This point of intersection **B** is the Maximum Dry Density, in this case 103.4 pounds per cubic foot (1656 kg/m^3), Figure 15.

To obtain Optimum Moisture, proceed downward vertically from point **B** as indicated by solid line **4** to intersect the horizontal leg (abscissa) at point **C**. The percentage shown at point **C** is the Optimum Moisture, in this case 19.6 percent, Figure 15.

Record the Maximum Density (Column I) and Optimum Moisture % (Column J) on Form 582B as shown in Figure 11.

If point **A** falls to the right of the Maximum Density curve, the soil is too wet. The moisture content should be reduced by drying the sample and the test repeated.

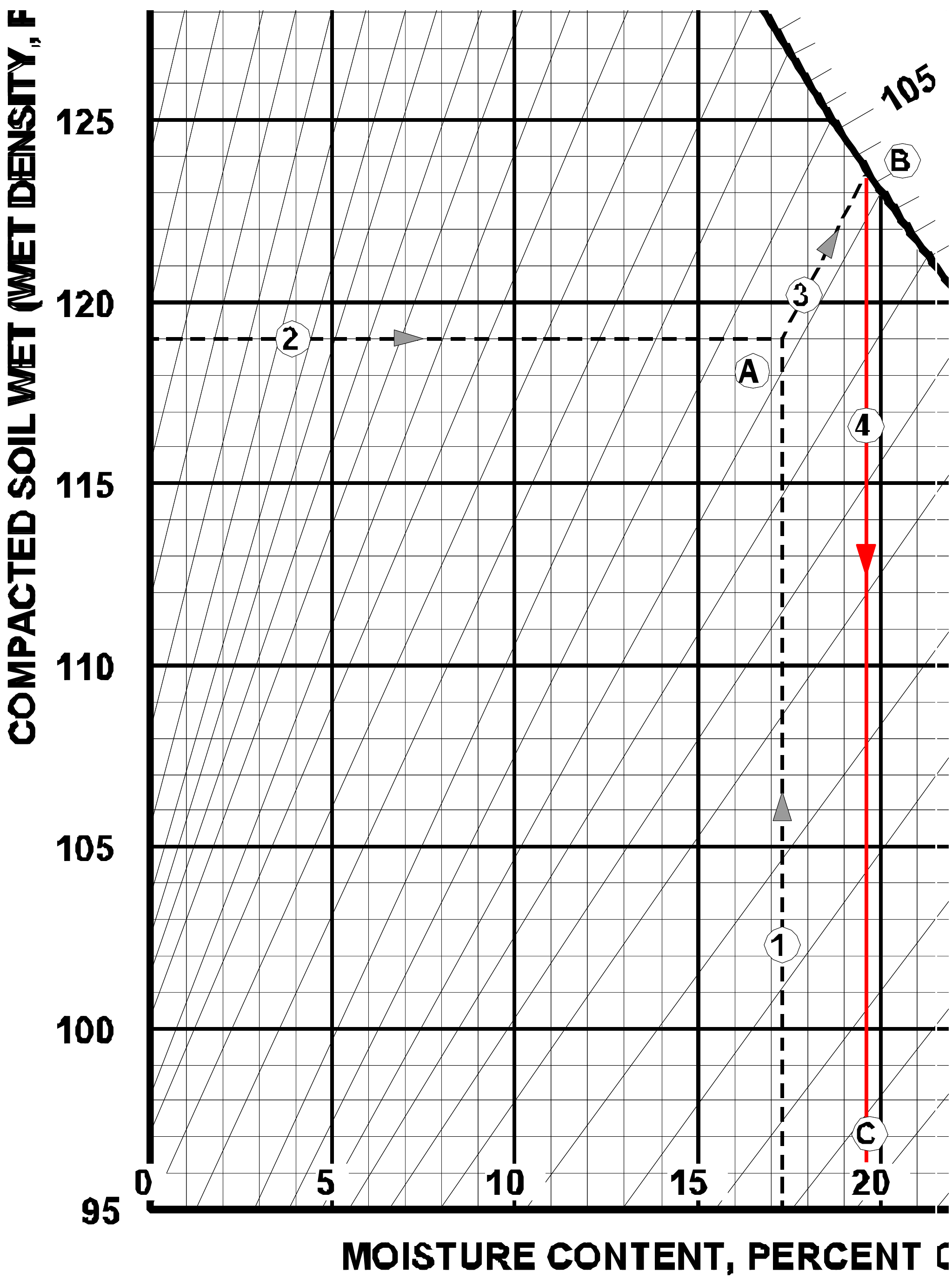

Figure 15. Steps 1, 2, 3 and 4

6. PRECAUTIONS IN PERFORMING THE ONE-POINT T-99 TEST

Experience has shown that the following items are important to keep in mind when performing the One-Point T-99 Compaction Test:

1. Establish a new Maximum Density any time the material changes (minimum of one per day).
2. Have the sample thoroughly broken up by running it through the screen before compacting the mold.
3. Pound within a moisture range from optimum to 4 percent below optimum. The closer to optimum the moisture content is, the more accurate the test will be.
4. Be sure that the clamp on each section is tight.
5. Be sure that the wing nuts on the base plate are secured with equal tension.
6. Place the mold on a solid block that is supported on firm soil or pavement.
7. Hold the rammer vertically so that it will fall freely.
8. Drop the 5.5 pound (2.5 kg) rammer weight freely for each 12 inch (305 mm) blow.
9. Use exactly 25 blows on each layer.
10. Place 3 equal layers in the mold.
11. Use enough material in the third layer so that when compacted, the material extends ¼ to ½ inch (5 to 15 mm) above the top of the mold. If the third layer is not above the top of the mold, repeat the test.
12. When using the Chart, use the Compacted Soil Wet (Column H) and Moisture % (Column B).
13. If the point on the Chart obtained by plotting the Compacted Soil Wet and Moisture % falls to the right of the Maximum Density curve, the sample is above Optimum Moisture content. Dry the sample and repeat the test.
14. On Form 582B, record the Maximum Density (Column I) and the Optimum Moisture % (Column J) obtained from the Chart.
15. In making entries on Form 582B, interpolate decimal fractions by using the grid lines given on the Chart.
16. Additional precautions for weighing and moisture sampling in this test and all others are given in the Appendix to this Handbook.

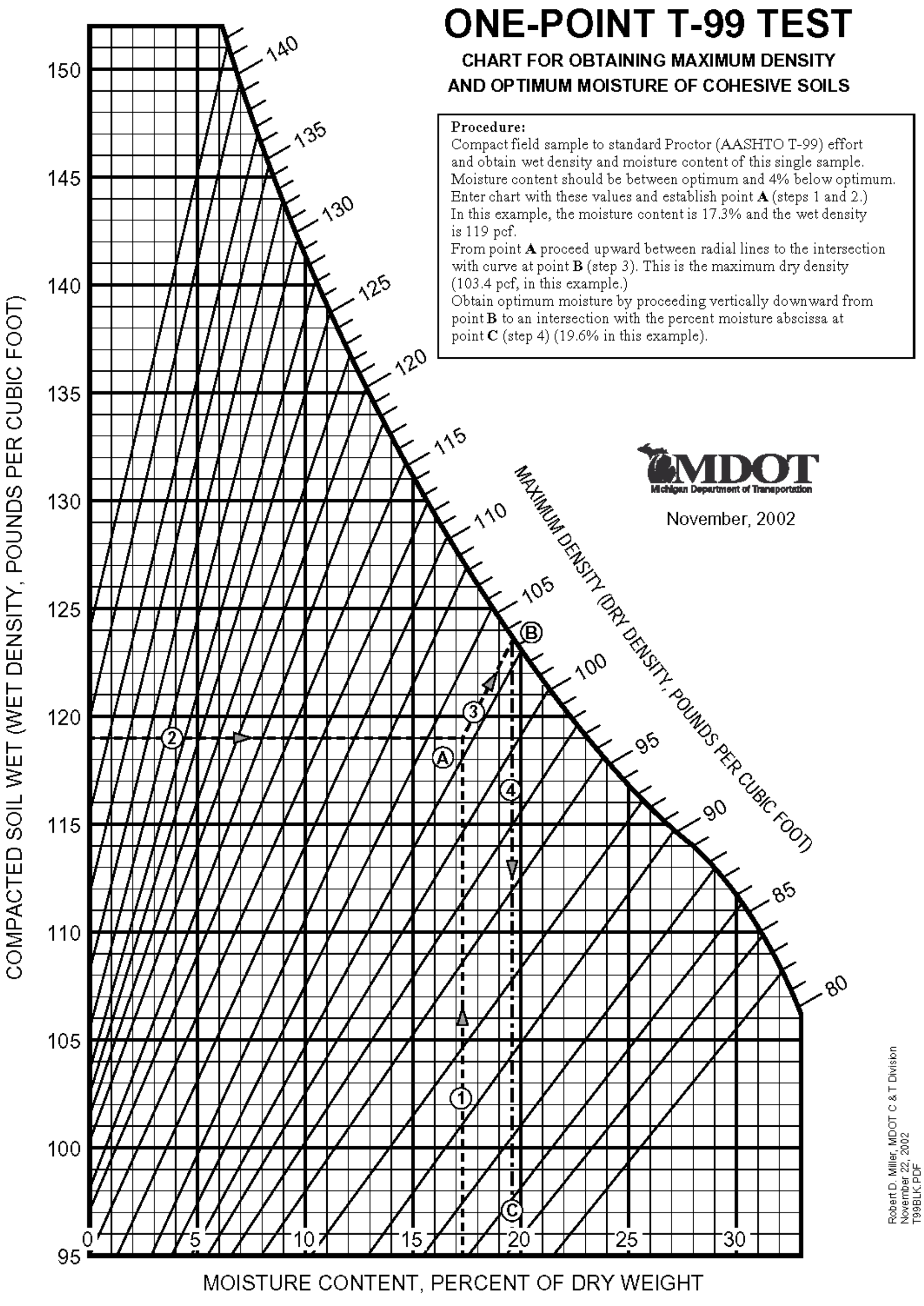

Figure 16. One-Point T-99 Chart

THE AASHTO T-99 TEST

1. DESCRIPTION

The department uses AASHTO Designation T-99 (Method C, Modified) as a referee or supplemental test to the One-Point T-99 Test to determine the Maximum Density of soils having a loss-by-wash greater than 15 percent. It is usually used by the inspector at the direction of the Area Density Supervisor. The equipment used is the same as that used for the One-Point T-99 Test (Figure 1) except for the One-Point Chart.

2. PREPARING AND COMPACTING THE SAMPLE

A representative sample, approximately 5000 grams, is taken from the soil to be tested. This sample should be thoroughly broken up by running it through the screen as shown in Figure 7. The coarse material retained on the screen is then visually inspected. Stones estimated to be larger than 1 inch (25 mm) are removed and replaced with an equivalent weight of smaller stone. The replacement stone shall be less than 1 inch (25 mm) but still large enough to be retained on the screen. This process completed as quickly as possible to avoid loss of moisture through evaporation. The coarse material retained on the screen is now added back to the sample.

The test should be started with the soil having a moisture content approximately 4 percent below optimum, which is determined by the hand cast. Figure 17 (left) shows a cast of soil having approximately this moisture content. At 4 percent below optimum, the cast will barely hold together, is readily friable, and will break easily with minimal hand pressure as shown in Figure 17 (right). It may be necessary to either add water or to dry the sample to obtain the desired moisture content. When water is added, the sample should be thoroughly mixed and run through the screen a second time. If the sample is too wet, it should be dried by running it through the screen and spreading it out on top of the density box.

Figure 17. Appearance of soil cast close to Optimum Moisture (left), and easily broken under minimal pressure (right)

The Proctor mold is then assembled and placed on a hardwood block, supported on firm ground or existing pavement, but not on the tailgate of the pickup truck. A layer of soil is placed in the mold in a quantity sufficient to fill one-third of its volume after compaction. The soil is then compacted in the mold by 25 blows of a 5.5 pound (2.5 kg) rammer, dropping 12 inches (305 mm) as shown in Figure 9. While compacting the soil, the rammer should be moved about the soil surface in the mold to obtain uniform compaction of each layer. It is important that the rod be held straight and the rammer weight dropped freely since it is a standard compactive effort. Any increase or decrease in the effort may materially affect the test's accuracy. A second layer of soil is added, filling another one-third of the volume of the mold after compaction. This too is compacted by 25 evenly distributed blows. The third and final layer is added, including enough soil to extend slightly above the top of the mold, after compaction. The third layer is compacted by 25 evenly distributed rammer blows. After the collar has been removed, the compacted soil column should extend ¼ to ½ inch (5 to 15 mm) above the top of the mold as shown in Figure 10 (top). If the soil column does not extend above the mold or if the soil column extends more than ½ inch (15 mm) above the mold, the test should be repeated.

The material is struck-off even with the top of the mold using the strike-off bar, as shown in Figure 10 (bottom). If pebbles encountered at this level are disturbed, they may either be pushed down or replaced by soil pressed down firmly with the strike-off bar.

3. WEIGHING THE SAMPLE

Next, the base plate is removed and the mold is weighed to the nearest gram (Figure 12). This weight is recorded in Column D (Wet Soil + Mold) on the density form (Form 582B). The volume of the mold and its weight when empty are painted on its side. This weight is recorded in Column E (Mold) and this volume in Column C (Volume Mold).

4. COMPLETING THE TEST PROCEDURE

The sample is removed from the mold by loosening the handle on the mold and pushing out the soil. The moisture content of the soil is determined by the calcium carbide gas pressure meter ("Speedy"). Refer to section I, pages 1-12. The Moisture % is entered in Column B of Form 582B. Complete the computations through Column H (Compacted Soil Wet) as shown in Figure 11. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing Column G (Wet Soil, lbs.) by the volume of the sample (Column C).

5. COMPLETING THE FULL TEST CURVE

The soil remaining in the mold is again broken up by running it through the screen and mixed with the remainder of the original sample. Water is added to raise the moisture content approximately 2 percent. An experienced inspector can judge moisture content by the feel and appearance of the soil. A new inspector should weigh the total sample and compute 2 percent of that weight to determine the amount of the water needed. The water is added and the sample is thoroughly mixed by working the soil through the screen until the water is uniformly distributed throughout.

After the sample has been broken up and mixed, the same procedure (compacting three layers in the mold, obtaining the moisture content, and determining the Compacted Soil Wet) is followed. This procedure is repeated until there is a decrease in the Compacted Soil Wet (Column H). Ordinarily this will require 4 or 5 molds of varying moisture contents to determine moisture-density results for the complete curve.

6. DETERMINING MAXIMUM DENSITY AND OPTIMUM MOISTURE

A graph is then prepared with a horizontal leg (abscissa) showing Moisture % and the vertical leg (ordinate) showing the Compacted Soil Wet values in pounds per cubic foot (kg/m^3). The Compacted Soil Wet and moisture content from each test are plotted on the graph. A smooth parabolic curve is then drawn through these points.

The apex or high point of the parabolic curve gives the Maximum Density and Optimum Moisture of the particular soil. The Maximum Density is recorded in Column I and Optimum Moisture % in Column J. It can be seen after plotting a curve why it is necessary to have at least four points to establish a definite peak. Two points are needed on each side of optimum to establish the slopes of the parabolic curve, which are nearly straight lines.

7. PRECAUTIONS IN PERFORMING THE AASHTO T-99 TEST

This test establishes a moisture-density relationship; thus, it is important that the compactive effort is standard and uniform throughout the entire series of molds to ensure accuracy of the results. Experience has shown that the following items are important to keep in mind when performing this test:

1. Establish a new Maximum Density any time the material changes (minimum of one per day).
2. Have the sample thoroughly broken up by running it through the screen before pounding.
3. Be sure that the clamp on the collar and mold are tight.
4. Be sure that the mold is seated squarely on the base and the wing nuts are secured with equal tension.
5. Place the mold on a solid block that is supported on firm soil or pavement.
6. Hold the rammer vertically so that it will fall freely.
7. Drop the 5.5 pound (2.5 kg) rammer weight freely for each 12 inch (305 mm) blow.
8. Use exactly 25 blows on each layer.
9. Reposition large stones away from the sides of the mold and away from other stones to prevent voids.
10. Place 3 equal layers in the mold.

11. Use enough material in the third layer so that, when compacted, the material extends ¼ to ½ inch (5 to 15 mm) above the top of the mold. If the third layer is not above the top of the mold, repeat the test.

12. Break up and screen the sample thoroughly and mix the water evenly into the sample before each succeeding test is started.

13. Pound enough molds at varying moisture contents to provide at least 2 points on each side of optimum for the graph.

14. Record Maximum Density (Column I) as well as Optimum Moisture % (Column J) on Form 582B, as obtained from the plotted curve.

15. Additional precautions for weighing and moisture sampling in this test and all others are given in the Appendix to this handbook.

THE ONE-POINT MICHIGAN CONE TEST

1. DESCRIPTION

An adaptation of the Michigan Cone Test is the One-Point Michigan Cone Test which derives its name from the fact that only one cone need be compacted. The One-Point Michigan Cone Test is used to determine Maximum Density of granular soils having a loss-by-wash of 15 percent or less. This includes aggregate base courses and Granular Material Classes I, II, and III. Research has shown that the One-Point Michigan Cone and Michigan Cone Test produce higher Maximum Density in granular soils than the AASHTO T-99 Test.

The equipment for this test is shown in Figure 2. This consists of an inverted funnel-shaped mold (cone) having a solid bottom at the large end, a stopper, a solid wood pounding block, a plastic water bottle, and a One-Point Michigan Cone Chart, Figure 18.

2. PREPARING, COMPACTING, AND WEIGHING THE SAMPLE (SAND OR GRAVEL)

A sample from the In-Place Density test of approximately 3500 grams is used in this test. A 10 by 10 inch (250 by 250 mm) pan (furnished in all density kits) filled level to the top usually contains enough material.

For the One-Point Michigan Cone Test, soil moisture content shall be between **5 percent and optimum moisture**. With experience, an inspector can determine this by "feel" and appearance or, if in doubt, by checking the moisture content with the moisture meter ("Speedy"). In many cases, water will need to be added. A plastic jug is in each density kit for this purpose. If water needs to be added, be sure the water is evenly mixed throughout the sample.

Enough soil is placed in the cone to fill it about one-third of its **height after compaction**. It is then pounded 25 times or more by raising the cone above the wood pounding block and striking it sharply, flat on the block's end grain (Figure 19). A second layer is added, filling the cone about two-thirds of its **height after compaction**, and pounded 25 times or more. The third layer, which fills the cone to the top, is added and pounded another 25 times or more. **After the third layer has been compacted, the cone is again filled to the top and then 10 blows or more are continued, holding a hand or stopper over the opening. Material is added at intervals to keep the mold full. Continue pounding until no further consolidation occurs (Figure 20). A common error in this test is to discontinue the blows before it is certain that no more material can be compacted into the cone.** If free water appears at the top of the cone, the material is saturated. The sample's moisture content should be reduced and the test repeated.

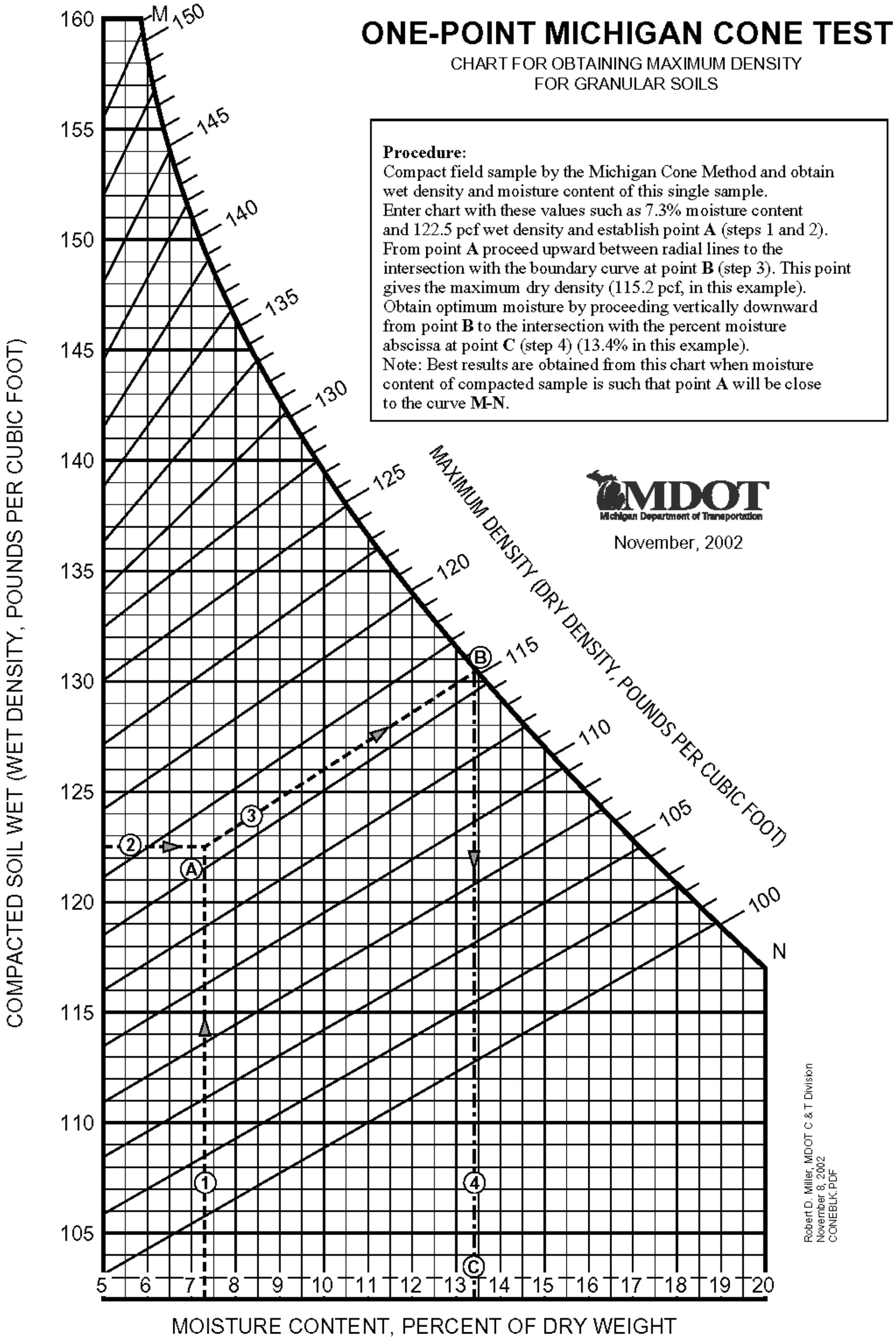

Figure 18. One-Point Michigan Cone Test Chart

Figure 19. Striking cone on block

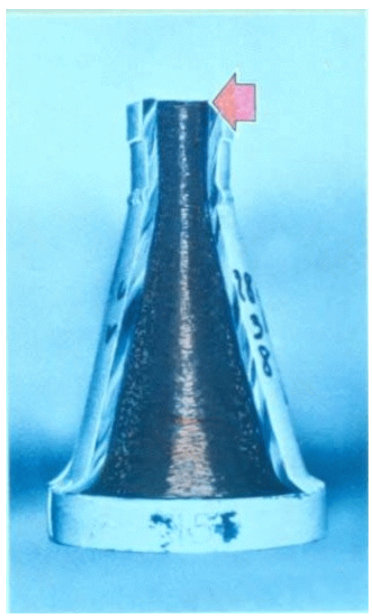

Figure 20. Cross-section of properly compacted cone mold

DETERMINATION OF MAXIMUM DENSITY (Soil & Bituminous)									
			DENSITY DETERMINATION						
TEST NO.	MOIS-TURE %	VOLUME MOLD CU. FT.	WET SOIL + MOLD g	MOLD g	WET SOIL g	WET SOIL lbs.	COMPACTED SOIL WET PCF	MAX DENSITY PCF	OPTIMUM MOISTURE %
1	2	3	4	5	6	7	8	9	10
1	7.3	0.0458	3818	1273	2545	5.61	122.5	115.2	13.4

NOTE:
To convert (g) to (lbs.):
Wt. (g) ÷ 453.59 = Wt. (lbs.).
To convert (m^3) to ($ft.^3$):
Vol. (m^3) ÷ 0.02832 = Vol. ($ft.^3$).

CHART STANDARDS	
DENSITY	MOISTURE
2757 / 2702	755 / 725
OPERATING STANDARDS	
DENSITY	MOISTURE
2710	736

BITUMINOUS MIX DESIGN PCF

REMARKS

Figure 21. Entries and computations for the One-Point Michigan Cone Test

After the cone is fully compacted, the material is leveled off the top using a straight-edge or the stopper (Figure 20). The cone is then weighed to the nearest gram. The weight is recorded in Column D (Wet Soil + Mold) as indicated in Figure 21.

The volume and the weight of the cone are painted on the bottom of the cone. The volume of the mold is recorded in Column C (Volume Mold), and the weight is recorded in Column E (Mold).

After the cone has been weighed, obtain a moisture sample from the center of the cone. Empty the cone by striking the open end **(not the sides of the cone)** on the wood block.

Note: The cone should be checked periodically for accuracy by the Area Density Supervisor. The weight and the volume of the cone should never be changed in the field. These values can only be changed when the cone is recalibrated.

3. DETERMINING MOISTURE CONTENT (SAND OR GRAVEL)

The percent moisture from the In-Place Density test results shall be used if the existing moisture is between 5 percent and a point short of saturation. If the sample has to be dried or have water added, then determine the moisture content by the calcium carbide gas pressure meter (“Speedy”). Refer to section I, pages 1-12. Record the resulting Moisture % in Column B of Form 582B.

Complete the computations through Column H (Compacted Soil Wet) as shown in Figure 21. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing Column G (Wet Soil, lbs.) by the volume of the sample (Column C).

4. DETERMINING MAXIMUM DENSITY AND OPTIMUM MOISTURE

Maximum Density is found by applying the Moisture % (Column B) and the Compacted Soil Wet (Column H) values to the One-Point Michigan Cone Test Chart, shown in Figure 18.

Assume that the results from a One-Point Michigan Cone Test are as follows: Compacted Soil Wet (Column H) (or "Wet Density") is 122.5 pounds per cubic foot (1962 kg/m³) and the Moisture % (Column B) (or "Moisture Content") is 7.3 percent. Locate the Moisture Content on the horizontal leg (abscissa) and the Wet Density on the vertical leg (ordinate) and then project lines on the Chart as indicated by the dashed line **1** and **2** to an intersection **A** (Figure 22). Next project point **A** upwards and to the right, as indicated by dashed line **3** to an intersection **B** with the outer boundary curve. This point of intersection **B** is the Maximum Dry Density or Maximum-Unit-Weight, in this case 115.2 pounds per cubic foot (1848 kg/m³) Figure 23. Enter the result in Column I (Maximum Density) of the "Determination of the Maximum Density" section as shown in Figure 21.

To obtain Optimum Moisture, proceed downward vertically from point **B** as indicated by dashed line **4** to intersect the horizontal leg (abscissa) at point **C**. The percentage shown at point **C** is the Optimum Moisture, in this case 13.4 percent (Figure 24). Enter the result in Column J (Optimum Moisture %) of the "Determination of the Maximum Density" section as shown in Figure 21.

If point **A** falls to the right of the Maximum Density curve, the soil is too wet. The moisture content should be reduced by drying the sample and the test repeated.

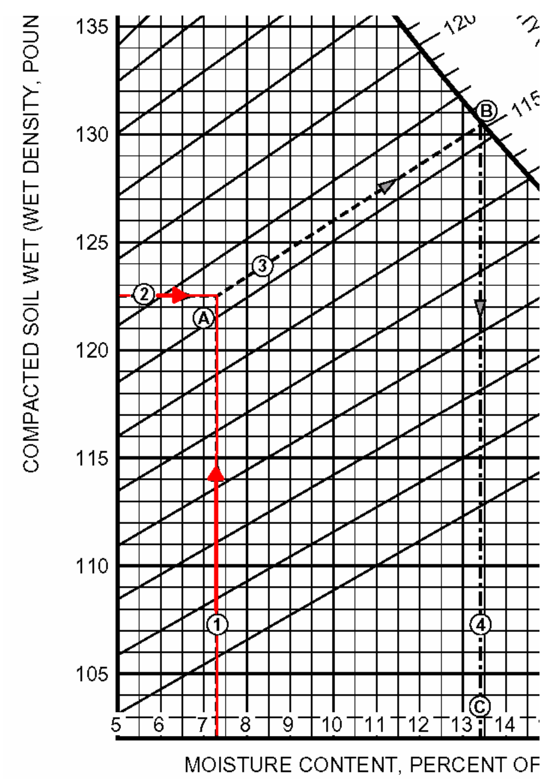

Figure 22. Steps 1 and 2

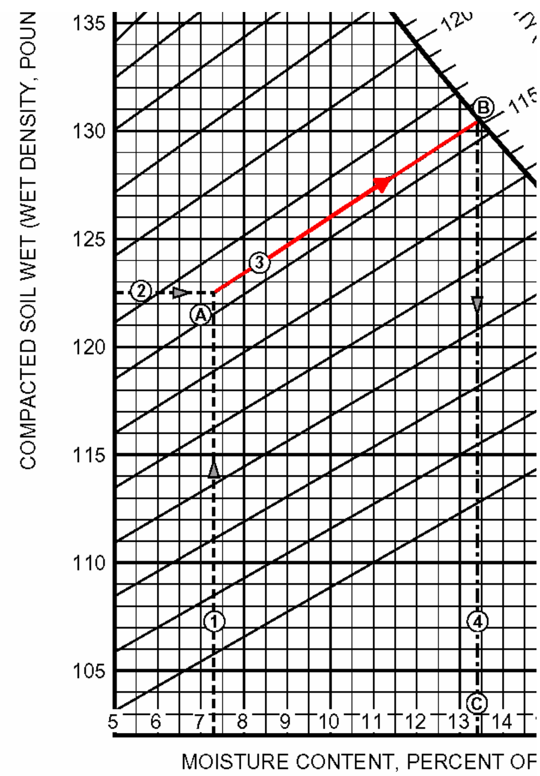

Figure 23. Step 3

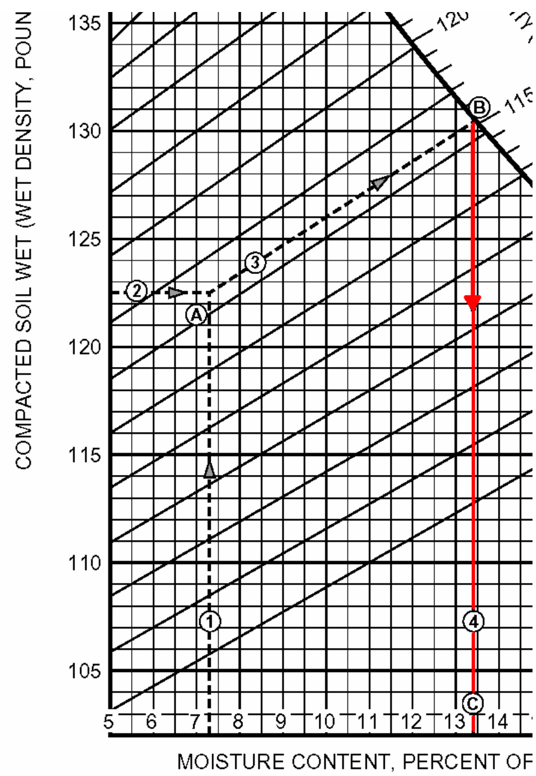

Figure 24. Step 4

5. PRECAUTIONS IN PERFORMING THE ONE-POINT MICHIGAN CONE TEST

Experience has shown that the following items are important to keep in mind when performing the One-Point Michigan Cone Test:

1. Establish a new Maximum Density any time the material changes (minimum of one per day).
2. Sample must have a moisture content between 5 percent and optimum moisture.
3. Use a hardwood pounding block placed on firm ground, not on the pickup tailgate.
4. Strike the cone squarely on the end grain of the block.
5. **Pound the cone until no more consolidation occurs.**
6. Empty the cone by inverting it and lightly striking the open end on the face of the block. **Do not empty by striking the cone on its side, as this can cause dents which may change the volume.**
7. Take the moisture sample from material at the center of the cone.
8. If the point on the Chart obtained by plotting the Compacted Soil Wet (Column H) and Moisture % (Column B) falls to the right of the Maximum Density curve, the sample is too wet. The sample should be dried and the test repeated.
9. Determine the Maximum Density and Optimum Moisture % to the nearest tenth.
10. Record the Maximum Density (Column I) and Optimum Moisture % (Column J) on Form 582B.
11. Clean out the cone after each test. Soil residue remaining in the cone may cause errors in weight and volume in the next test. Cleaning is easily done by shaking a few stones in it.
12. Check the empty cone weight periodically. If any change is observed, the cone should be recalibrated only by <u>qualified</u> personnel.
13. Maximum Density cannot be determined using a cone if the sample is saturated.
14. Additional precautions for weighing and moisture sampling in this test are in the Appendix to this handbook.

THE MICHIGAN CONE TEST

1. DESCRIPTION

The Michigan Cone Test is a series of cone tests used to determine Maximum Density of granular soils having a loss-by-wash of 15 percent or less. It is usually used as a referee or supplemental test to the One-Point Michigan Cone Test, by the inspector at the direction of the Area Density Supervisor. The equipment used is the same as that used for the One-Point Michigan Cone Test (Figure 2) except for the One-Point Michigan Cone Test Chart.

2. PREPARING, COMPACTING, AND WEIGHING THE SAMPLE (SAND OR GRAVEL)

The weight of the representative sample of sand or gravel used in this test is approximately 3500 grams. A 10 by 10 inch (250 by 250 mm) pan (furnished in all density kits) filled level to the top usually contains enough material.

For all granular materials, the moisture content should be at least **5 percent**. This may require the addition of water for most granular soils and aggregates. Mix the water thoroughly with the material.

Enough soil is placed in the cone to fill it about one-third its **height after compaction**. It is then pounded 25 times or more by raising the cone above the wood pounding block and striking it sharply, flat on the block's end grain, Figure 19. A second layer, filling the cone about two-thirds its **height after compaction**, is added and pounded 25 times or more. The third layer, which fills the cone to the top, is added and pounded another 25 times or more. **After the third layer has compacted, the cone is again filled to the top and then 10 blows or more are continued, holding a hand or stopper over the opening. Material is added at intervals to keep the mold full and then 10 blows or more are continued until no further consolidation occurs, Figure 20. A common error in this test is to discontinue the blows before it is certain that no more material can be compacted into the cone.** If free water appears at the top of the cone, the material is saturated. The sample's moisture content should be reduced and the test repeated.

After the mold is fully compacted, the material is leveled off the top, using a straight-edge or the stopper (Figure 20). The cone is then weighed to the nearest gram. This weight is recorded in Column D (Wet Soil + Mold) as shown in Figure 21. The volume of the cone and its weight when empty are painted on its bottom. This volume should be recorded in Column C (Volume Mold), and this weight in Column E (Mold).

The weight of the cone should be checked periodically for any change. The cone should occasionally be checked for volume accuracy by the Area Density Supervisor, since the repeated poundings may bulge the bottom of the cone and change its volume. If any change is observed, the cone should be recalibrated only by qualified personnel for weight and volume.

After the cone has been weighed, obtain a moisture sample from the center of the cone sample. Empty the cone by striking the open end **(not the sides of the cone)** on the wood block.

3. DETERMINING MOISTURE CONTENT (SAND OR GRAVEL)

The moisture content is determined by the calcium carbide gas pressure meter ("Speedy"). Refer to section I, pages 1-12. The Moisture % is entered in Column B of Form 582B.

4. DETERMINING MAXIMUM DENSITY OF GRANULAR SOIL OTHER THAN PROCESSED AGGREGATES

Complete the computations through Column H (Compacted Soil Wet) as shown in Figure 21. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing Column G (Wet Soil, lbs.) by the volume of the sample (Column C).

If the result of Column H (Compacted Soil Wet) is less than 120 pounds per cubic foot (1922 kg/m^3) and the moisture content is between 5 percent and optimum, the Maximum Density is the result of one cone test. Enter this result in Column I (Maximum Density).

If the result of Column H (Compacted Soil Wet) is more than 120 pounds per cubic foot (1922 kg/m^3), a series of two or three cone tests should be repeated at varying moisture contents between 5 percent and a point short of saturation. Suggested moisture contents for the cone series are 7, 9, and 11 percent. The highest test results of this series of cones is the Maximum Density or Maximum-Unit-Weight and is entered in Column I.

5. DETERMINING MAXIMUM DENSITY: AGGREGATE BASE COURSES AND SURFACE AGGREGATES

Research has shown that moisture content does have an appreciable effect on Maximum-Unit-Weight of gravel. This weight is greatest within a 5 to 8 percent moisture content. Thus the Maximum Density of aggregates is determined at a moisture content ranging from 5 to 8 percent, as follows:

1. Run a series of cone tests with moisture content of the aggregate at different points within the 5 to 8 percent range. Two or three points within this range generally should be sufficient to determine the highest unit weight. For example, one test could be run at approximately 5 percent moisture, a second at approximately 6 percent moisture, and a third at approximately 7 percent moisture.

    a) If the cone is saturated (free water appears at the top of the cone), reduce the moisture content but not below **5 percent**. If the cone test is run on saturated aggregate, the results may be inaccurate.

    b) If the aggregate in the cone exhibits the "swell" effect (rises slightly above the top of the cone), reduce the moisture content but not below **5 percent**.

2. The highest test result of the series of cones within the 5 to 8 percent moisture range is the Maximum-Unit-Weight or Maximum Density.

6. PRECAUTIONS IN PERFORMING THE MICHIGAN CONE TEST

Experience has shown that the following items are important to keep in mind when performing the Cone Michigan Test:

1. Establish a new Maximum Density any time the material changes (minimum of one per day).

2. Use a hardwood pounding block placed on firm soil, not on the pickup tailgate.

3. Strike the cones squarely on the end grain of the block.

4. **Pound the cone until no more consolidation occurs.**

5. Empty the cone by inverting it and lightly striking the open end on the face of the block. **Do not empty by striking the cone on its side, as this can cause dents which may result in changes in volume.**

6. As nearly as can be estimated, take the moisture sample from material at the center of the cone.

7. Clean out the cone after each test because soil residue will cause errors in weight and volume in the next test. This is easily done by shaking a few stones in it. Do not dry the cone over an open flame.

8. Check the empty cone weight periodically. If any change is observed, the cone should be recalibrated only by qualified personnel.

9. The Area Density Supervisor should check the weight and volume of the cone periodically.

10. Do not perform cone tests on saturated sands or gravels.

11. Additional precautions for weighing and moisture sampling in this test and all others are given in the Appendix to this handbook.

THE MICHIGAN MODIFIED T-180 TEST

1. DESCRIPTION

The Michigan Modified T-180 Test is a modification of AASHTO T-180 (Method C) Test. This test is used to determine the Maximum Density of recycled mixtures containing pulverized Hot Mix Asphalt (bituminous) and/or concrete pavement used as aggregate base course. This test also applies to stabilized Hot Mix Asphalt (bituminous) material used as aggregate base course. The test is performed at existing moisture content, short of saturation, on material with a maximum top size of 1 inch (25 mm). The Maximum Density is determined on a wet weight basis which is calculated using the total weight of the sample, which includes both the weight of the solids and the weight of the water.

The equipment used for the Michigan Modified T-180 Test is shown in Figure 3. It consists of a cylindrical mold (Proctor mold) of 4 inches (100 mm) in diameter, with a detachable collar and base plate; a 10 pound (4.5 kg) rammer with an 18 inch (457 mm) drop; a sharp-edge strike-off bar; and a wood pounding block.

2. OBTAINING AND COMPACTING THE SAMPLE

The sample of material to establish the Wet Maximum Density should be obtained from the exact site of the In-Place Test. This is very important because the Wet Maximum Density is established at the **existing moisture content**. Enough material should be obtained to fill the 10 by 10 inch (250 by 250 mm) pan and thoroughly mixed for even distribution of the existing moisture.

The Proctor mold is assembled and placed on a hardwood block, supported on firm ground or existing paved surface. Enough material is placed in the mold to fill one-fifth of its volume after compaction. The material is then compacted in the mold by 25 blows of the 10 pound (4.5 kg) rammer weight, dropping 18 inches (457 mm) as shown in Figure 25. While compacting the material, the rammer should be moved about the material surface in the mold to obtain uniform compaction of the layer. It is important that the rod be held straight and the rammer weight dropped freely since it is a standard compactive effort. Any increase or decrease in the effort can significantly affect the accuracy of the test. A second, third, and fourth layer of material is added, each layer being compacted by 25 blows and each layer filling approximately one-fifth of the volume of the mold. The fifth and final layer of material is then added, including enough material to extend ¼ to ½ inch (5 to 15 mm) above the top of the mold after compaction. The fifth layer of material is also compacted by 25 blows. After the collar has been removed, the compacted soil column should extend ¼ to ½ inch (5 to 15 mm) above the top of the mold as shown in Figure 26. If the soil column does not extend above the mold, or if the soil column extends more than ½ inch (15 mm) above the mold, the test should be repeated.

The material is struck-off even with the top of the mold using the strike-off bar as shown in Figure 27. Large voids in the surface of the molded sample should be filled, using the fines of the sample and pressed down with the strike-off bar and struck-off.

Figure 25. Recycled material being compacted in the mold

Figure 26. Mold with collar removed and recycled material ¼ to ½ inch (5 to 15 mm) above the top of mold

Figure 27. Mold with the material struck-off even with the top of the mold

3. WEIGHING THE SAMPLE

Next, the base plate is removed and the mold and sample are weighed to the nearest gram (Figure 28). This weight is recorded in Column D (Wet Soil + Mold) on the Form 582B as shown in Figure 29. The volume of the mold and its weight when empty are painted on its side. This volume is recorded in Column C (Volume Mold) and this weight in Column E (Mold).

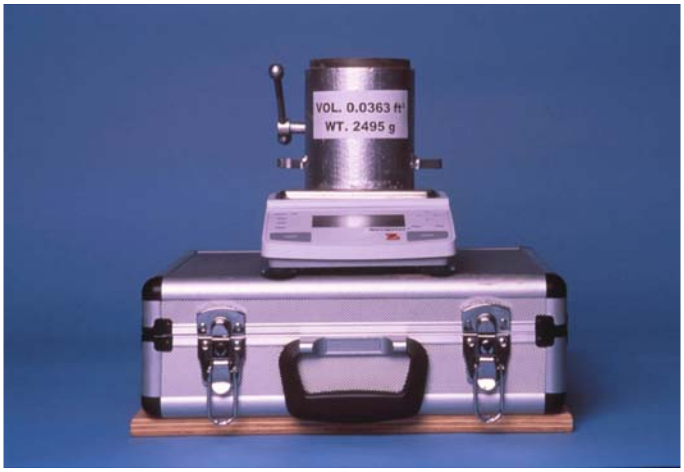

Figure 28. Weighing the mold plus recycled material to the nearest gram

4. DETERMINING WET MAXIMUM DENSITY

The Wet Maximum Density can now be determined by completing the computations through Column H (Compacted Soil Wet) as shown in Figure 29. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing Column G (Wet Soil, lbs.) by the volume of the sample (Column C). The Compacted Soil Wet (Column H) is also the Wet Maximum Density and should be recorded in Column I (Maximum Density).

A new Maximum Density should be determined any time the material changes, or the moisture changes ± 1.5 percent. Because the Maximum Density is determined at the existing moisture content, more Maximum Density tests may be necessary than might be expected. For example: After running an In-Place Density Test and determining a Wet Maximum Density, the In-Place Density Test did not meet requirements. The contractor, before applying more compactive effort, elects to add moisture to the area of the failing test. After the failing area is rerolled, the area is retested with another In-Place Test. If the same Maximum Density was used for the retest, the test would probably pass, not because of the additional effort so much as from the addition of moisture.

It is possible to obtain passing retests just by adding moisture if the previous Maximum Density obtained at a lower moisture content is still used. Whenever moisture is added to a failing area, a new Wet Maximum Density shall be established when the In-Place Density retest is run.

Michigan Department of Transportation
0582B (TEST)

MOISTURE AND DENSITY DETERMINATION

NUCLEAR METHOD

DISTRIBUTION: ORIGINAL - Project Engineer, COPIES - Area Density Supervisor, Density Technology (Lansing).

*SEE REVERSE SIDE

DATE	CONTROL SECTION ID	JOB NUMBER	ROUTE NO. or STREET	GAUGE NO.
9/4/02	33081	26673A	I-96 at Creyts Rd.	101233

DENSITY INSPECTOR	CERTIFICATION NO.	PROJECT ENGINEER (MDOT)	PROJECT MANAGER	PROJECT MANAGER PHONE NO.
D.E. Land	09056-0354	C.E. Fill	J.B. Junk	555-1212

DETERMINATION OF IN-PLACE DENSITY

TEST		WET DENSITY			MOISTURE			DRY DENSITY			LOCATION OF TEST				
ORIGINAL	RECHECK	COUNTS (DC)	TEST DEPTH inch	WET DENSITY PCF	COUNTS (MC)	MOIS-TURE PCF	MOIS-TURE %	DRY DENSITY PCF	MAX DENSITY PCF	PERCENT OF COM-PACTION	STATION	DISTANCE FROM ℄ FT LEFT	DISTANCE FROM ℄ FT RIGHT	DEPTH BELOW PLAN GRADE FT	ITEM OF WORK *
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		1963	4	139.6	79		5.6		139.7	99.9	112 + 50	6.0		1.0	BAB
2		2045	4	137.4	76		5.5		139.7	98.4	113 + 50	6.0		1.0	BAB
3		1906	4	140.8	95		7.5		142.7	98.7	113 + 90	4.0		1.0	BAB
4		1945	4	139.9	90		6.7		142.7	98.0	114 + 50	6.0		1.0	BAB
5		1921	4	140.6	91		6.8		142.7	98.5	115 + 45	6.0		1.0	BAB

DETERMINATION OF MAXIMUM DENSITY (Soil & Bituminous)

TEST NO.	MOIS-TURE %	VOLUME MOLD CU. FT.	DENSITY DETERMINATION: WET SOIL + MOLD g	MOLD g	WET SOIL g	WET SOIL lbs.	COMPACTED SOIL WET PCF	MAX DENSITY PCF	OPTIMUM MOISTURE %
A	B	C	D	E	F	G	H	I	J
1	5.6	0.0363	4795	2495	2300	5.07	139.7	139.7	
3	7.5	0.0363	4845	2495	2350	5.18	142.7	142.7	

NOTE:
To convert (g) to (lbs.):
Wt. (g) ÷ 453.59 = Wt. (lbs.).
To convert (m^3) to ($ft.^3$):
Vol. (m^3) ÷ 0.02832 = Vol. ($ft.^3$).

CHART STANDARDS

DENSITY		MOISTURE	
2739	2685	664	638

OPERATING STANDARDS

DENSITY	MOISTURE
2698	655

BITUMINOUS MIX DESIGN PCF

REMARKS

DENSITY INSPECTOR'S SIGNATURE D. E. Land

AGENCY/COMPANY Lansing TSC

Figure 29. Entries and computations for Michigan Modified T-180 Test

5. PRECAUTIONS IN PERFORMING THE MICHIGAN MODIFIED T-180 TEST

Experience has shown the following items are important to keep in mind when performing the Michigan Modified T-180 Test:

1. Determine the Wet Maximum Density at the **existing moisture content** (normally several will have to be performed each day).
2. Perform the In-Place Tests in the “Asphalt Mode”.
3. Use the same material as used for the In-Place Test.
4. Make sure the pounding block is placed on a compacted grade surface or existing pavement.
5. Hold the rammer perpendicularly so the weight falls freely for each 18 inch (457 mm) blow.
6. Use exactly 25 blows on each layer.
7. Compact 5 equal layers in the mold.
8. Use enough material in the fifth layer so that when compacted the material extends ¼ **to** ½ **inch** (5 to 15 mm) above the top of the center section of the mold.
9. Establish a new Wet Maximum Density any time the material changes or **moisture changes** ± **1.5%**.
10. Enter Wet Marshall Density as a **Marshall** value.

THE MICHIGAN MODIFIED MARSHALL TEST

1. DESCRIPTION

Although the department no longer uses the Michigan Modified Marshall Test, it is still an accurate method of determining Maximum Density In-Place and can be found in previous editions of this handbook.

THE TWELVE-INCH (300 mm) LAYER METHOD TEST

1. DESCRIPTION

The Twelve-Inch (300 mm) Layer Method Test is a test which utilizes the T-99 Test or the Michigan Cone Test, depending upon the loss-by-wash of the material being tested. If the material being tested has a loss-by-wash of more than 15 percent, the inspector should use the T-99 Test. The Michigan Cone Test would be used on material with a loss-by-wash of 15 percent or less.

In the normal T-99 and Michigan Cone Tests, either a series of molds or One-Point Charts are used to establish a Maximum Density. The Twelve-Inch (300 mm) Layer Method Test utilizes one mold at the existing field moisture to establish the Maximum Density.

2. OBTAINING, PREPARING, COMPACTING, AND WEIGHING THE SAMPLE

In running this test the inspector should use the material obtained directly under the In-Place Test. After the In-Place Test is run, a sample of the material, large enough to prepare a mold, is obtained. If the material being tested is granular, it should be mixed to distribute the moisture evenly throughout the sample. If the material being tested is cohesive, it should be worked through the screen; the stones that are 1 inch (25 mm) or less left on the screen are put back in the sample and mixed. Then, either a cone mold or T-99 mold would be run following the steps described previously in this handbook, depending upon the percent loss-by-wash of the material.

After the mold is fully compacted, the material is struck off even with the top of the mold, using a straight-edge or stopper. The mold is then weighed to the nearest gram. The weight is recorded in Column D (Wet Soil + Mold). The volume of the mold and its empty weight are painted on the bottom or side of the mold. The volume should be recorded in Column C (Volume Mold) and the weight in Column E (Mold).

The weight of the mold should be checked periodically. The mold should periodically be checked for volume accuracy by the Area Density Supervisor, since repeated usage may change the volume of the mold. When changes are observed, the mold should be taken out of service and returned for recalibration.

3. DETERMINING MOISTURE CONTENT

The Moisture % obtained from the In-Place Density Test is entered in Column B.

4. DETERMINING MAXIMUM DENSITY

Computations are then completed through Column H (Compacted Soil Wet) at the bottom of Form 582B. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing Column G (Wet Soil, lbs.) by the volume of the sample (Column C).

Since this is the Twelve-Inch (300 mm) Layer Method Test, the Maximum Density is established at existing field moisture content. Maximum Density is obtained by dividing the Compacted Soil Wet (Column H) by the [Moisture % (Column B) + 100]. This answer is multiplied by 100 and entered in Column I (Maximum Density).

5. PRECAUTIONS IN PERFORMING THE TWELVE-INCH (300 MM) LAYER METHOD TEST

Experience has shown the following items are important to keep in mind when performing the Twelve-Inch (300 mm) Layer Test:

1. Make sure the wood pounding block is placed on firm soil, not on the pickup tailgate.
2. The loss-by-wash determines whether to use the T-99 or Cone.
3. Pound the mold in the correct manner.
4. The Maximum Density is determined using material directly under the In-Place Test.
5. Use the existing field moisture to establish the Maximum Density.
6. Use the formula: Maximum Density = 100 X Compacted Soil Wet ÷ [Moisture % + 100].
7. Never use the One-Point Charts to establish the Maximum Density.

THE DENSITY IN-PLACE (NUCLEAR) TEST

1. DESCRIPTION

The department is currently using the Troxler Model 3440 portable nuclear gauge for field density control.

The gauge contains radioactive sources and is regulated by the NRC and the US DOT.

The gauge uses a Scalar display which records the radiation emitted from a source which passes through the soil and is picked up by detector tubes. The principle involved is that dense materials absorb more radiation than less dense material. The lower the Scalar display reading, the higher the density of the material.

The gauge also measures the amount of moisture in the material being tested. This is accomplished by the gauge source emitting “fast” neutrons and only detecting “slow” neutrons. The hydrogen in the moisture slows the “fast” neutrons to a rate of speed the detector tubes can pick up and count. The more moisture, the more hydrogen, resulting in more “slow” neutrons for the tubes to detect, thereby giving a higher moisture content.

When not in use, the source rod must be fully retracted in the SAFE position. When the Troxler gauge is lifted by the handle, the source rod automatically returns to the SAFE position.

2. LOCATION AND FREQUENCY OF TEST

The Density In-Place Test should be taken in those areas of fill (embankment) or backfill that appear to be least compacted. The test area is selected by watching the movement of the contractor’s compaction equipment. If the tests are run in the visibly poorer areas and they meet specification requirements, it may be assumed that the remainder of the test section also meets specifications. The controlled density specifications require each layer to be compacted to a minimum of 90, 95, 98, or 100 percent of Maximum Density, depending on the item of work. Details on frequency of testing are given in the Appendix to this handbook.

The gauge offers the option to test by Direct Transmission or Backscatter. Always use Direct Transmission tests on soil materials. The Backscatter test is used only on Hot Mix Asphalt (bituminous) mixtures.

3. TROXLER MODEL 3440

The Troxler gauge, as shown in Figure 30, is a direct transmission gauge. Mechanically, this gauge is the same as the 3411B gauge. Electronically and functionally, this gauge is state-of-the-art. This model also contains a microprocessor which is programmed to perform a much wider range of functions and larger memory storage for ease of operations. The gauge is more user friendly by prompting the user and displaying more test information in the display window.

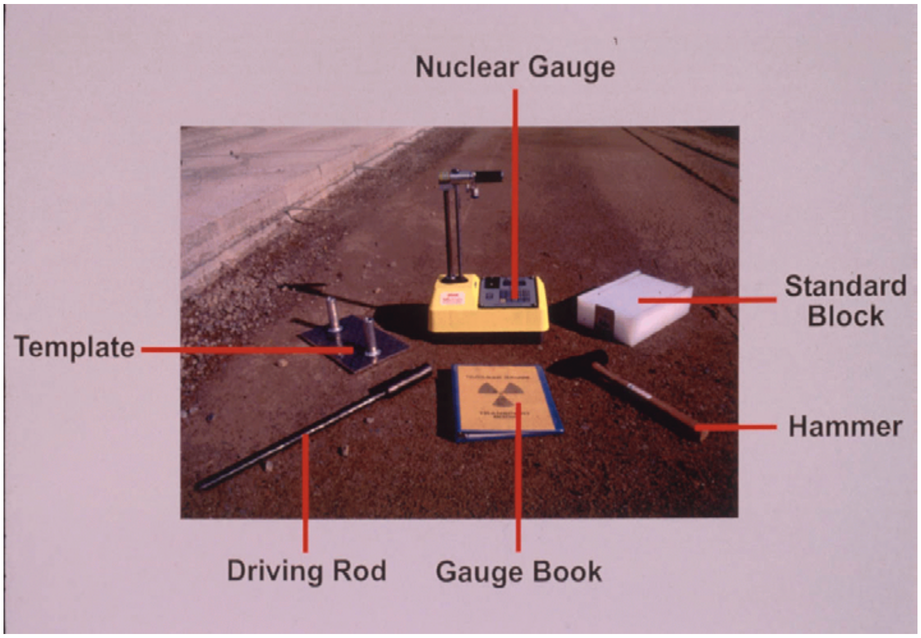

Figure 30. Troxler Model 3440 nuclear gauge

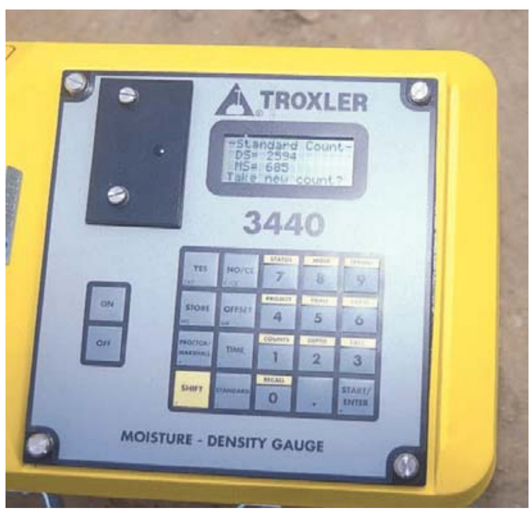

Figure 31. Troxler 3440 controls

3.1 Keys Description

Below is a functional description of the keys of the 3440 control panel as shown in Figure 31 and each key's function:

KEYS	DESCRIPTION
YES EXIT	Answers displays prompts. Permits exit from the calculator mode.
NO/CE C/CE	Answer display prompt/Clear last entry. Clears calculator entry.
STATUS 7	(SHIFT function) Display status of gauge functions. Number key.
MODE 8	(SHIFT function) Asphalt or Soils selection. Number key.
SPECIAL 9	(SHIFT function) Provides access to special functions. Number key.
STORE MS	To store data in gauge memory. Memory store function for the calculator mode.
OFFSET MR	Select measurements offsets. Memory recall function for the calculator mode.
PROJECT 4	(SHIFT function) To enter, view, or erase a project Number key.
PRINT 5	(SHIFT function) Download data Number key.
ERASE 6	(SHIFT function) Erase data Number key.
PROCTOR/ MARSHALL +	Proctor or Marshall value selection. Plus sign for calculator functions.
TIME -	Selects time interval for testing and measurement. Minus sign for calculator functions.
COUNTS 1	(SHIFT function) For displaying the last reading. Number key.
DEPTH 2	(SHIFT function) Automatic or manual depth operation. Number key.
CALC. 3	(SHIFT function) To access the calculator mode. Number key.
SHIFT x	Activates all SHIFT functions modes. Multiplication sign for calculator functions.
STANDARD ÷	Provides access to standard count mode. Division sign for calculator functions.
RECALL 0	(SHIFT function) To recall data for viewing Number key.
.	Decimal point key
START/ENTER =	See manual text. Equals sign for calculator functions